

## FIRE IN ECOSYSTEM DISTRIBUTION AND STRUCTURE: WESTERN FORESTS AND SCRUBLANDS

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### ABSTRACT

Fire plays an important role in determining structure of forests and scrublands throughout the West. Distribution and structure of vegetation depends upon topography, climatic regime, and fire regime. Six fire regimes are defined based on fire frequency and intensity, varying from frequent, low-intensity surface fires to very long return interval, stand replacement fires. In certain western forests and scrublands fire suppression for the past 50 to 100 years has led to longer intervals between fires, increases in surface and crown fuels, changes in forest structure, and sequential impacts on fire intensity, postfire age structure, species composition, fuel accumulation, and both horizontal and vertical pattern. Better understanding of fire regimes is basic to our management of western ecosystems.

KEYWORDS: western forests, fire regimes, fire frequency, fire intensity, scrublands.

### INTRODUCTION

Fire plays a major role in the function of most of the forests and scrubland ecosystems of the western United States. In many ecosystems, fire controls the age structure and species composition of the vegetation and creates a mosaic of vegetation types on the landscape (Heinselman 1978). Fire acts with different frequencies and intensities, depending upon the vegetation and topography involved, as well as the climatic regimes which determine the coincidence of ignitions with given burning conditions. Thus vegetation composition and structure depend on climate, fire frequency, and intensity, while fire frequency and intensity in turn depend on vegetation structure, topography, and climatic regimes.

Because of almost annual coincidence of ignitions with suitable burning conditions, western forests, such as those found in the Sierra Nevada, have frequent fires. Because such fires are frequent, they are of low intensity. By contrast even though ignitions are equally as frequent in certain Rocky Mountain forests, they do not coincide as frequently with dry fuel conditions. Thus these fires have a longer recurrence interval and are either more intense surface fires that kill all nonresistant species or are crown fires with shorter or longer return intervals.

Forest and scrublands in the West can be grouped into the following four broad formations adapted from Oosting's (1956) climax formations of North America: (1) subalpine forest, (2) montane forest, (3) woodland, and (4) scrubland. These formations--based on climatic regime and topography--range from vegetation found in moist, higher elevation, north exposures to that found in drier, lower elevation, south exposures. These formations occur in altitudinal zones on the principal mountain ranges in the West: the Rocky Mountain, Cascades, Sierra Nevada, and Coast Ranges as well as on Great Basin and Intermountain ranges. Distribution of plant communities or habitat types in the western United States has been covered broadly by Oosting (1956) and in more regional detail by Daubenmire and Daubenmire (1968), Franklin and Dyrness (1973), Munz and Keck (1959), and Pfister and others (1977).

#### Impact of Fire Frequency on Species Composition

Frequency of fire is critical in selecting those species that will continue as part of the vegetation of a given area. A species cannot survive if fire is introduced too often or too early or deferred too long in its life cycle (Hendrickson 1972). For example, with nonsprouting species, survival in a given area may be threatened by fires which occur before there has been time for a seed pool to accumulate or after the plant's longevity has been exceeded and the store of seed is lost (Gill 1979). The significance of fire frequency in determining the species composition aspect of forest structure through time is illustrated when fire burns often enough to prevent a fire-dependent Douglas-fir (Pseudotsuga menziesii) or lodgepole pine (Pinus contorta) forest from changing to a nonfire-dependent, shade tolerant fir, cedar-hemlock, or spruce-fir forest.

#### Impact of Fire Frequency/Intensity on Vegetation Mosaic

The horizontal pattern or mosaic of vegetation in a given area is made up of contrasting age classes, successional stages, and vegetation types created by recurring fire over long- or short-term rotation periods (Heinselman 1978). The scale of the vegetative mosaic is influenced by frequency and intensity of fire as well as the topographic base on which fire occurs. In relatively flat or gently rolling country where long-term intense crown fires or stand-replacing surface fires are characteristic, patches of the mosaic may cover thousands of acres. In steep, broken terrain, such as the Sierra Nevada, where low-intensity fires burn frequently, the patches may be less than 0.25 acres (0.1 ha) in size (Bonnicksen 1975). Whatever the size of patches or aggregations involved, the overall mosaic changes little, as long as the frequency and intensity of fire characteristic of that vegetation and topography continues; the individual aggregations are periodically rearranged by fire and succession, like pieces of a kaleidoscope (Bonnicksen and Stone 1978, Heinselman 1978).

#### Fire Regimes

Fire is important in so many ecosystems that it is becoming less meaningful to refer to fire-dependent vs. fire-independent systems. Instead we need to speak of systems with varying "fire regimes" made up of such factors as fire frequency and intensity (Heinselman 1978, Sando 1978), season (Gill 1973), pattern (Keeley 1979), and depth of burn (Methven 1978). In order to emphasize the wide range of fire characteristics found in the West and to make comparisons between them, I have organized what is known about the impact of fire frequency and intensity on vegetative structure around a modification of the fire regimes described by Heinselman (1978):

- (1) frequent, low-intensity surface fires (1- to 25-year return interval);
- (2) infrequent, low-intensity surface fires (more than 25-year return interval);

- (3) infrequent, high-intensity surface fires (more than 25-year return interval);
- (4) short return interval, stand-replacement fires (25- to 100-year return interval);
- (5) variable regime: frequent, low-intensity surface fires and long return interval, stand-replacement fires (100- to 300-year return intervals); and
- (6) very long return interval, stand replacement fires (more than 300-year return intervals).

Certain major forest types are covered only briefly because little is known at present about the relationship between forest structure and fire frequency and intensity in those types. More thorough treatment has been given here to certain other forest types--particularly the sequoia-mixed conifer forest--because information is available, even though the type covers a more restricted geographic range.

An intense fire can either burn through the tops of crowns of trees, thus killing trees as a "crown fire," or it can simply girdle or heat-kill fire-sensitive trees by intense burning at ground or surface level. In either case, the stand of trees or segment of the forest is partially or totally killed. However, only in the most short-term sense can this be called simply a "stand-destroying" fire. Because at the same time it is killing the existing group of trees, the fire is providing a set of conditions--sometimes involving the seedbed, opening of closed cones, or stimulation of sprouting species--which lead to replacement of the old forest or scrubland by a new vegetation. In this paper, therefore, a high-intensity surface fire or crown fire which kills most of the existing vegetation is also referred to as a "stand-replacement" fire as used by Gabriel (1976), Habeck (1976), Antos (1977), Sneek (1977), Van Wagner (1978), and Arno (1980).

Fire frequencies are difficult to compare in a meaningful way between different studies of various forest types and geographic regions unless similar-sized units are being compared. Kilgore and Taylor (1979) used "frequency" to mean "interval between fires on the same piece of ground...calculated from records found on a single tree or a cluster of trees growing fairly close together." C. E. Van Wagner (personal communication) feels there is only one basic parameter, namely, "the average number of years between fires at a point." He notes, however, that "fire cycle" is the same concept if it is defined as the number of years to burn an area equal to the whole area in question (see also Methvan 1978). This is similar to Heinselman's (1973) "natural fire rotation," and "fire return interval" (Tande 1977) embodies the same idea. "Fire frequency" or "fire cycle" can be contrasted with "fire incidence" which has been defined as "the interval between fires which burned someplace in a particular-sized unit of the forest, such as a drainage, but not necessarily involving the same point" (Kilgore and Taylor 1979). The importance of this distinction is that "frequency" reflects fuel, climatic, and ignition factors inherent in the ecosystem or forest type, while "fire incidence" also is affected by the size of the area being observed. Thus in a study of a giant sequoia (Sequoiadendron giganteum)--mixed conifer forest, the patchy fire regime was recorded every 17-23 years on individual trees, every 9-17 years in 1- to 2-acre (0.4- to 0.8-ha) clusters, every 5-9 years somewhere in 40-acre (16-ha) study sites, and every 2 years somewhere in 2,500-acre (1 000-ha) drainage (Kilgore and Taylor 1979). Obviously, the larger the unit size, the greater the numbers of fires and the shorter the intervals between them without any basic change in ecosystem function. By contrast, where fires are generally extensive, as in chaparral, recurrence intervals would often be similar for both single-acre and 100-acre or larger units. Hence, fire incidence alone is an incomplete description of the fire regime of a forest and a far less useful measure than either "fire frequency" or "fire cycle."

In discussing fire's role in the evolution of plant attributes, Keeley (1979) has pointed out that for that purpose, a "natural" fire frequency should include only lightning ignitions. For other purposes, such a distinction may be unnecessary. In any case, with the exception of sequoia-mixed conifer forest (Kilgore and Taylor 1979), there is little quantitative data upon which to base judgment of what proportion of presettlement ignitions were started by lightning or aboriginal sources. Hence, in this paper, I will not attempt to separate these two sources of ignition, although aboriginal burning was clearly significant in certain ponderosa pine and giant sequoia forests, and perhaps in other vegetation types as well.

Most studies of fire history and fire ecology of certain forest types specify intensity (if at all) in subjective and nebulous terminology such as "cool/light" or "hot/severe." Use of categories such as (1) low-intensity surface fires, (2) medium to high-intensity surface fires (torching), and (3) high-intensity crown fires is preferable, provided a range of fire intensity is noted for each class. Sando (1978) has suggested use of intensities greater than 1200 Btu/ft/sec to separate high-intensity fires from low- to moderate-intensity fires. Ecologists often appear to lack a clear understanding of fire behavior and its importance to the sound interpretations of fire effects (Van Wagner and Methven 1978). So it is not yet possible to relate quantitative intensity measurements, such as heat production per second per unit length of fire front (Byram 1959, Van Wagner 1965, Albini 1976), to specific changes in the ecosystem. Part of the past disagreements about the role of fire in a given forest or habitat type can probably be attributed to this lack of data refinement and documentation (Kilgore 1973b). Future field and laboratory studies must strive to resolve this problem by correlating fire effects with fuel, fire behavior, and environmental parameters.

#### FREQUENT, LOW-INTENSITY SURFACE FIRES

Frequent, low-intensity surface fires were characteristic of presettlement ponderosa pine (*Pinus ponderosa*) and giant sequoia-mixed conifer forests (Weaver 1951, Cooper 1960, Biswell 1967, Kilgore and Taylor 1979). Even certain Douglas-fir and western larch (*Larix occidentalis*) forests in the Rocky Mountains were kept open for centuries by such frequent natural burning (Arno 1980) along with insect epidemics and other mortality factors.

In his summary of the effects of fire on western forests, Weaver (1974) quoted a number of early explorers who, in describing the forest structure of Sierra Nevada montane forests, referred to "the inviting openness of the Sierra woods...trees of all species standing more or less apart in groves, or in small, irregular groups...with openings that have a smooth, parklike surface, strewn with brown needles and burs" (Muir 1894). One even spoke of being able to ride their horses "at a free gallup through the forest" which seemed like a vast covered hall where "in stately groups, stand tall shafts of pine" (King 1871). Although these statements reflect what we think sizable portions of these patchy forests were like, we should be cautious in extending these specific comments to imply that all areas of these forests were this open at all times.

One of these same early-day observers (Muir 1901) described the intensity of a fire he saw in 1875 in what is now Sequoia National Park, Calif., which resulted from this open type of structure and contrasted it with the intensity found in the dense chaparral scrubland and in certain dense forests of the Rocky Mountains and the Cascades:

The fire came racing up the steep, chaparral-covered slopes... in a broad cataract of flames.... But as soon as the deep forest was reached, the ungovernable flood became calm, like a torrent entering a lake, creeping and spreading beneath the trees.... There was no danger of being chased and hemmed in, for in the main forest

belt of the Sierra, even when swift winds are blowing, fires seldom or never sweep over the trees in broad, all-embracing sheets as they do in the dense Rocky Mountain woods and in those of the Cascade Mountains of Oregon and Washington. Here they creep from tree to tree ...allowing close observation....

The presettlement structure of pine and mixed conifer forests in the Sierra Nevada and intensity of fire which is possible because of that structure was described by Show and Kotok in 1924:

The virgin forest is uneven-aged, or at best even-aged by small groups, and is patchy and broken; hence it is fairly immune from extensive, devastating crown fires. Extensive crown fires, though common in the forests of the western white pine region, are almost unknown in the California pine region. Local crown fires may extend over a few hundred acres, but the stands in general are so uneven-aged and broken and have such a varied cover type that a continuous crown fire is practically impossible.

#### Ponderosa Pine Forests

Average fire frequencies in presettlement ponderosa pine forest varied from 6 to 19 years in different parts of its range (Wright 1978), with 5 to 12 years found in Arizona and New Mexico (Weaver 1951), 8 to 10 years being characteristic of ponderosa pine in California (Show and Kotok 1924, Wagner 1961, McBride and Laven 1976); 8 to 18 years in various parts of Oregon and Washington (Keen 1940; Weaver 1955, 1959; Soeriaatmadja 1966; Hall 1976); and 6 to 10 years reported from the Bitterroot National Forest in Idaho and Montana (Arno 1980). In forests containing a mixture of ponderosa pine and white fir (Abies concolor) in southern Oregon, McNeil and Zobel (1979) found mean intervals between fires that varied from 9 to 42 years at given sites.

Early studies of stand development in ponderosa pine by Weaver (1943, 1967) and Cooper (1960, 1961) help interpret structural changes with fire exclusion. In Arizona ponderosa pine forests, Cooper (1960) noted that under presettlement conditions, low-intensity surface fires, set by lightning or Indians, burned through the forest at regular intervals of 3 to 10 years. These fires served as thinning agents and played an important role in the cyclical process of stand development.

In describing a simplified form of this process, Weaver (1967) stated: "Periodic burning causes development of uneven-aged stands, comprised of even-aged groups of trees of various age classes." The system operated because low-intensity fire killed more small pines under canopies of larger trees than in openings. It did so because a surface fire would burn with greater intensity through heavy accumulations of flammable needles, cones, and bark scales which build up under larger trees than in the lighter and often less continuous fuels in the openings. But at various sites throughout the forest, even-aged groups of trees were killed by insects, disease, lightning, or windthrow. These groups of dead trees were gradually reduced to ashes in subsequent fires, leaving openings in the forest canopy within which pine seeds could germinate and young pines survive. (Another possibility would be that fire by chance would miss certain sites and allow enough fuel buildup that overstory trees would be killed in subsequent fires, leading to an opening.) Within such openings, the small accumulation of needles from these newly established young pines would not support a surface fire, although dry grasses and forbs in the openings would. Hence, until the pines were large enough to build up fuels beneath their own canopy, fires were not intense enough to kill them; and by the time they did contribute such heavier fuels, many of them were large enough to survive the low-intensity surface fires.

patterns of establishment of Douglas-fir (Pseudotsuga menziesii) in redwood stands at 200- to 500-year intervals on mesic sites, presumably related to infrequent, high-intensity surface fires. Inland, on higher, drier sites, redwood dominance is reduced and Douglas-fir age classes suggest a return interval of 50 to 100 years for fires which open the forest canopy to the extent necessary for fir establishment. In its northern range, redwood appears to reproduce at replacement rates (about 1 tree/acre every 50 years) in the absence of fire. With the exception of Douglas-fir, associated trees such as tanoak (Lithocarpus densiflora), hemlock (Tsuga heterophylla), and grand fir (Abies grandis), like redwood, appear to reproduce successfully both with and without ground fires.

#### SHORT RETURN INTERVAL, STAND-REPLACEMENT FIRES

Chaparral and quaking aspen (Populus tremuloides) are two vegetation types which illustrate a short return interval between stand replacement fires. Both forms have all aboveground vegetation killed by periodic, intense burning--either crown fire or high-intensity surface fires, but each survives by sprouting from root crowns or by reseedling. In addition, several types of woodland and scrub vegetation are prevented from invading grasslands by periodic crown fires. Pinyon-juniper and sagebrush scrub illustrate this response.

##### Chaparral

Large sections of chaparral are found in California and Arizona, often occurring as a band of vegetation between grasslands below and forests above. In California alone, it covers 11 million acres (4.5 million ha) (Bentley 1967). Chaparral is best developed or most extensively distributed on the steep slopes and shallow soils of southern California (Menke and Villasenor 1977).

Slope aspect is an important factor in the chaparral environment, in part determining which species make up a local chaparral community and even succession following fire (Hanes 1971). Chamise (Adenostema fasciculatum) is a prominent member of the climax chaparral, often forming almost pure stands in some areas. Other sites are dominated by various species of manzanita (Arctostaphylos spp.), ceanothus (Ceanothus spp.), and scrub oak (Quercus spp.). Species of the latter three genera also make up much of the patches of chaparral that occur within conifer forests (Biswell 1974).

Recent work by Byrne (1978) provides evidence that wildfires were an important part of the California chaparral environment long before European man arrived on the scene. Using data gathered from ancient charcoal fragments deposited in marine sediments between 1400 and 1550 A.D., Byrne's (1978) preliminary conclusions were that prehistoric fires in chaparral and woodland of the Los Padres National Forest area of southern California "occurred less frequently than during the modern period, but those that did occur were of greater intensity and aerial extent. We estimate the recurrence interval of these fires to be anywhere from 20 to 40 years."

Fire has likely been an important factor in chaparral for a long time. The plant species involved have developed two main strategies for surviving burning: many species exhibit vigorous sprouting ability following fire; others have seedcoats that are altered by fire, and thus germination of seeds is favored.

Present frequencies of fire in this type of scrubland are reported to vary from less than 10 years in sections of the south coastal region of California through 20 to 25 years in the north coastal regions to as much as 50 to 100 years in manzanita chaparral growing at 4,000 ft (1 220 m) elevations on northern slopes.<sup>1/</sup> Under fire

<sup>1/</sup> Material in preparation for a textbook on fire ecology by Henry A. Wright and Arthur W. Bailey.

suppression conditions today, many areas have not burned for 60 to 100 years. Based on work in Sequoia National Park, Calif., Parsons (1976) concluded that chamise regained much of its prefire structure within 14 years, and that by 35 years, "...it shows all the characteristics of a mature stand, most of the successional subshrub forms having disappeared."

The dramatic impact of interaction between fire frequencies and intensities on the one hand and vegetation structure and reproductive strategies on the other is illustrated by recent work in southern California chaparral. Keeley and Zedler (1978) believe chaparral is adapted to both short and long fire-free intervals, a reflection of the unpredictability of fire in that environment. They suggest a model which includes both (1) a short fire cycle which favors sprouting shrubs over those reproducing entirely from seed; and (2) a long fire cycle in which "sprouters" and "seeders" coexist. In the short cycle (25 years), there are fewer dead shrubs before the fire, more potential resprouts, less intense fires, lower fire-caused mortality of sprouting shrubs, and smaller openings for seedlings. In the long cycle (100 years), however, there are more dead shrubs before the fire, fewer potential resprouts, higher intensity fires, more fire-caused mortality of sprouting shrubs, and larger openings for seedlings. They predict that with the present fire cycle of every 20 to 30 years, both sprouting and seedling species regenerate but, over long periods of time, sprouting species may gain an advantage.

Keeley (1977) believes that southern California chaparral may have evolved under relatively long fire-free intervals. Similar conclusions were reached by Sauer (1977) who suggested that chaparral of the Santa Monica Mountains evidently "was adapted to a regime of infrequent, large, intense, nonselective fires, which has not been substantially altered by man." Evidence of this was presented by Byrne and others (1977).

In the case of the chaparral adjacent to conifer forest in Sequoia National Park, Parsons (1976) believed that fire prevention and suppression have led to the "formation of an unnatural, highly flammable, nearly uniform, old-aged...brush community." He was concerned that with the known high frequency of lightning fires in the area and increasing recreational use, an unnaturally intense fire would both destroy the vegetation mosaic that currently exists and threaten the nearby groves of giant sequoia.

Parsons (1976) indicated that existing fuel accumulations need to be reduced so that more natural fires could be allowed to burn at frequent intervals. Once fire has restored a natural mosaic of age classes and community types, "these age-class boundaries would then function, along with topographic features, as natural fuel breaks for limiting the size of future fires and thus perpetuating the mosaic" (Parsons 1976). Philpot (1977) shares the same concern that without fire for periods of 50 years or longer, age-class boundaries become less distinct and chances increase for larger, more catastrophic fires. Byrne and others (1977), however, believe that some presettlement fires were large and catastrophic.

#### Quaking Aspen

Studies by Loope and Gruell (1973) indicate that in presettlement times successful regeneration of aspen stands was stimulated by fire. Hendricksen (1972) hypothesized fire frequencies of 50 to 100 years for aspen. Loope (1971) noted that while occasional aspen may live to 200 years in the absence of intense fire, they tend to deteriorate after 80 to 100 years and be replaced by conifers. This is true because aspen is fairly short-lived, is susceptible to many diseases, and cannot survive or reproduce in the shade of competing conifers such as Douglas-fir (Loope 1971, Gruell and Loope 1974). Although the aboveground portion of aspen is easily killed by fire, its root system is rarely damaged; hence aspen clones are perpetuated by fire, and aspen gets a headstart on competing conifers by root sprouting.

Clements (1910) found that aspen sprouts grew more rapidly after an intense fire than after a light fire. Horton and Hopkins (1966) also found that a fire intense enough to kill all aspen stems and remove litter and duff is desirable to produce prolific suckering, whereas low-intensity fire does not achieve this result. Gruell and Loope (1974) concluded that fire suppression during the past 50 to 70 years is a major factor contributing to the recent decline of aspen in Jackson Hole, Wyo.

#### Pinyon-Juniper Woodland

The pinyon-juniper association covers more than 43 million acres (17 million ha) in western North America (Wright and others 1979). Before livestock grazing was involved, fire, drought, and competition with grass jointly limited the distribution of juniper (Juniperus occidentalis).

Buckhardt and Tisdale (1976) report presettlement intervals between fires in western juniper stands in southwest Idaho comparable to the 13- to 18-year interval found by Keen (1940) for ponderosa pine forests. Such frequent fires kept junipers restricted to shallow, rocky soils and rough topography in many parts of the West. With initiation of livestock grazing, reduced competition from grasses has permitted pinyon (Pinus edulis) and juniper to invade adjacent grass and sagebrush communities; with reduced numbers of fires and lower intensity burning (without grass fuels), the juniper invasion has continued unchecked (Martin 1978, Wright and others 1979). In a study of two species of mistletoe that infest pinyon and juniper in Grand Canyon National Park, Ariz., Hreha (1978) found that fire was the most limiting factor on the mistletoe, and that the mistletoes and their hosts appeared to be in equilibrium.

Along the uplands in Mesa Verda National Park, Erdman (1970) found that recurrent fires had maintained a Gambel oak (Quercus gambelii)-serviceberry (Amelanchier utahensis) mountain brush vegetation as a fire climax. But under fire suppression policies, pinyon-juniper forest is gradually replacing the extensive shrub vegetation. Prescribed fire will kill pinyon and juniper less than 4 ft (1.2 m) tall (Wright and others 1979), but taller trees are more difficult to kill. Hence, to prevent invasion of grass and shrublands by pinyon and juniper, reburns are needed at least every 20 to 40 years.

#### Sagebrush Scrub

Sagebrush-grass vegetation covers at least 96 million acres (40 million ha) in the western United States, mostly below the pinyon-juniper zone (Wright and others 1979). Big sagebrush (Artemisia tridentata) is the principal fuel for free-running fires in the broad Great Basin Desert ecosystem which covers much of Nevada, southern Oregon, southern Idaho, and parts of Wyoming, Utah, and Arizona (Humphrey 1974). In presettlement times, minimum fire frequency in this community in northern Yellowstone National Park was 32 to 70 years (Houston 1973), and Wright and others (1979) felt 50 years is likely.

There has been little research on effects of fire in the sagebrush desert, perhaps because fires are rarely extensive in the ecosystem (Humphrey 1974). However, this high, cold desert or sagebrush desert is more subject to burning than the hotter, drier, more southerly Mojave, Sonoran, and Chihuahuan Deserts. This is true in part because the higher elevations and greater moisture permit growth of fire-supporting grasses and forbs beneath and between the sagebrush (Humphrey 1974). In addition, there is considerable fuel from adjacent juniper, pinyon-juniper, or grassland vegetation types that carry fires from these areas into the sagebrush type.

Fires have a major impact on such nonsprouting shrubs as Artemisia tridentata within the sagebrush-grass community, but specific responses vary with seasonal timing, intensity, and frequency of burning (Wright and others 1979). In degraded



big sagebrush/Thurber needlegrass (Stipa thurberiana) rangeland communities, north of Reno, Nev., wildfires killed the sagebrush, stimulated sprouting of two native shrubs, and allowed downy brome (Bromus tectorum), an "alien" annual grass, to dominate the study areas (Young and Evans 1978). The annual grass appears to provide an accumulation of fine fuel that readily ignites and carries fire to the widely spaced sagebrush plants, thus setting in motion a cyclic phenomenon leading toward conversion to an annual grassland.

Artemisia tridentata produces a growth ring that can be counted to determine age of plant or plant community (Ferguson 1960). In a study of shrub age structures on a mule deer winter range in Colorado, Roughton (1972) found an unusually large number of Artemisia individuals in the 55- to 59-year age class. This either suggested that some major mortality factor such as fire had occurred at about the turn of the century and "the population had not yet returned to equilibrium" (Roughton 1972) or there have been 60 years of poor conditions for reproduction since then. Future studies using this shrub age-dating technique may allow determination of age structures for a shrub population and in turn an interpretation of successional status and variations from predicted sequences which may result in part from fire impacts.

From a land management standpoint, to keep sagebrush in check, "prescribed fire can be a useful tool in many big sagebrush...communities if the fires are carefully planned...fires should not be too frequent and should be planned in early spring or after late summer" (Wright and others 1979). Particular species responses to fire must be understood to achieve whatever objective the land manager may have.

VARIABLE REGIME: FREQUENT, LOW-INTENSITY SURFACE FIRES  
AND LONG RETURN INTERVAL, STAND-REPLACING FIRES

High-intensity, stand-replacing crown fires occur in various forest types in the West. In certain types, however, the fire regime varies between relatively frequent, low- to moderate-intensity surface fires and long return interval crown fires, depending upon weather conditions and ignition factors in particular sites. When wind and other weather conditions are favorable for intense burning, the likelihood of an ignition leading to a high-intensity crown fire depends on such forest structural factors as: (1) the spacing of trees; (2) the quantity of crowns per unit area; (3) the amount and arrangement of surface fuels; and (4) how high the crown canopy is above the surface fuel heat sources (Brown 1975). Such intense fires have occurred periodically at more than 100-year intervals in lodgepole pine, western white pine (Pinus monticola), and western larch forests of the Rocky Mountains and in Douglas-fir and lodgepole pine forests in the Cascades (Fahnestock 1977).

Wellner (1970) felt that the age structure of most Northern Rocky Mountain forests supported the conclusion that fire in this region tends to be catastrophic, killing most trees in the forest. Recent studies (based on fire-scar and stand-age data) summarized by Arno (1980), however, indicate that "historic fires occurred with vastly different frequencies and had markedly different effects in this region's diverse forest environments." In some habitats, fires maintained many-aged, open stands of seral trees, while in others, fires destroyed and replaced stands. This was true, Arno (1980) points out, because fires burned at variable intensities "...resulting in a mosaic of stands that differed in tree species composition and age-class structure."

One fairly consistent conclusion by scientists and resource managers working in most areas of the Northern Rocky Mountains seems to be that there are few areas in which shade tolerant, climax forests of spruce (Picea sp.), fir (Abies sp.), hemlock (Tsuga sp.), and redcedar (Thuja plicata) have been allowed to develop. Instead, fire--whether frequent and low intensity or less frequent and of higher intensity--has repeatedly favored the development of stands of intolerant, fire-dependent species

the only species that continues to reproduce beneath the forest canopy" (Pfister and others 1977), with increased shade and soil moisture often playing important roles here. In the Selway-Bitterroot Wilderness of Montana, Habeck (1976) found that grand fir regeneration was spreading in all directions, into wetter, drier, and higher elevation sites. He concluded that expansion of the fire-sensitive grand fir may be a relatively new event related to fire suppression.

#### DISCUSSION

Gill (1979) noted that it is unfortunate when someone implies that either a wildfire or management fire will not harm vegetation because the flora is "adapted to fire." He points out rightly that this is an incomplete concept, and a better statement would be that, "the vegetation is adapted to a certain fire regime." The significance of this point is driven home by noting the broad range of frequencies and intensities which were found in presettlement forests and scrublands of the western United States, ranging from the frequent low-intensity surface fires of ponderosa pine to the very infrequent and high-intensity crown fires found in many spruce-fir forests. Frequent low-intensity burning would be just as out of place in spruce-fir forests as infrequent high-intensity crown fires are in naturally operating ponderosa pine ecosystems.

Yet, with fire having been suppressed in many western forests for the past 50 to 100 years, unnatural changes have been evolving slowly--even imperceptibly in some cases. This is leading to a sequence of events which may be developing for the first time ever. A conceptual model of this sequence of a sequoia-mixed conifer forest would show that suppression leading to longer intervals between fires would initially lead to increases in surface and crown fuels and to changes in the forest structure such that there would be (1) older age classes; (2) a denser forest (less openings); (3) a multilayered vertical structure; (4) an increase in ladder fuels; and (5) more shade tolerant species. This would next lead to increased probability of higher intensity surface fires with some individual tree crowns burning, and to sequential impacts on postfire forest structure, species composition, fuel accumulation, and both horizontal and vertical pattern. In turn, this would bring about changes in fire frequency and intensity. The unknown in such a model is how a new balance would be arrived at, as long as man puts substantial energy into fire suppression.

Such changes in the absence of fire during the past century or less are greatest in those forests which historically had a short return interval between fires and least in forests which had a very long return interval. For example, if the normal interval between fires is 300 years or more, the recent absence of fire for 50 to 100 years would be of little significance.

In certain northern forests, however, it appears that fire intensity is not a pure function of fuel buildup with age. Work by Van Wagner (1977) and Fahnestock (1977) suggests that crown fire potential is probably greatest at young and moderate age, then decreases as the stand matures. "Certainly the role of fire spread depends more on the quantity and arrangement of fire fuels than on the accumulation of downed logs" (Van Wagner 1978). Once breakup of the forest stand begins through death of certain older or weaker trees, there is a major increase in dead materials added to surface fuels and surface fire intensity might take a surge upward. Because of new openings in the crown canopy, however, continuous crown fires would then be less likely unless a well-defined conifer understory had arisen.

#### Plant Succession

Plant succession following fire does not necessarily follow a single pathway. As Cattellino and others (1979) point out, various species-specific attributes related to reproduction and survival determine the successional outcome when a given ecosystem is disturbed by fire. As an example, in the Northern Rocky Mountains, a community made

up of aspen, lodgepole pine, and western larch will have different outcomes depending upon the intervals between fires as they relate to the following life-history characteristics: (1) aspen's lifespan of 130 years and its vegetative reproduction; (2) lodgepole pine's lifespan of 250 years and its need for 20 years before mature cones are produced; and (3) larch's 300- to 400-year lifespan and its ability to disperse seeds widely from surrounding forests after a fire. If a community with aspen and lodgepole pine is burned less than 130 years after the last fire, both species will be present in the postfire succession. If the stand burns after 250 years, both species will be lost and larch will take over by seeding in from surrounding forests. If the stand burns in less than 20 years, lodgepole pine will be lost, but both aspen and larch would be part of postfire succession (Cattellino and others 1979). Thus, man-caused changes in fire frequency--through suppression or prescribed burning--can have major impact on the species composition and structure of a forest.

#### Insects, Parasites, and Disease

Brown (1975) and others have emphasized the importance of insects, parasites, and disease in modifying the structure of many western forests and, in turn, the frequency and intensity of subsequent fires. Relatively little quantitative work has been done on the effects of fire on plant diseases (Alexander and Hawksworth 1976, Parmeter 1977). Available evidence--particularly concerning fire and dwarf mistletoe (*Arceuthobium* spp.)--has been summarized by Alexander and Hawksworth (1975, 1976), Hardison (1976a, 1976b), Harvey and others (1976), Wicker and Leaphart (1976), and Parmeter (1977, 1978). The relationship between fire, insects, and forest structure has been discussed by Miller and Keen (1960) and Roe and Amman (1970).

In an overview of the impact of fire on pathogens, Parmeter (1977) concluded that, "Fire can alter disease activity in forests and scrublands directly by affecting the survival and development of pathogens or indirectly by affecting characteristics of plant communities, individual plants, or physical and microbial environments that influence pathogens." The relationship between fire and disease is complicated both by the variability of fire intensity and frequency and by the complexity of possible interactions between fire and disease.

In the absence of fire, numbers of trees infected, intensity of infection, and degree of damage increases with age of trees or stands and size of trees. The rate of spread through multistoried stands is also more rapid than through single-storied stands (Parmeter 1978).

Intense fires tend to have a sanitizing effect on infected stands giving lodgepole pine the edge over mistletoe, while partial burns create ideal conditions for rapid spread of mistletoe in even young stands (Alexander and Hawksworth 1976). Mistletoe, on the other hand, kills and stunts trees, causes spike tops and witches' brooms, which modify vertical structure of the forest, providing "ladders" for fire to ascend and consume tree crowns. This obviously increases fire hazard, flammability, and fire intensity. Fire may encourage spread of the mistletoe parasite by conversion of nonsusceptible climax spruce-fir forests to mistletoe-susceptible nearly pure stands of lodgepole pine (Alexander and Hawksworth 1976). At the same time, fire may limit development of natural genetic resistance to mistletoe by continually preventing survival of any trees that may have become somewhat resistant (Roth 1974).

Prescribed burning in pine plantations in the South reduced pine mortality and total infection by *Heterobasidion annosum* (*Fomes annosus*) root rot (Froelich and others 1978). The impacts of fire on the fungus were greatest where the disease was most serious. Although confirming field studies need to be carried out in western forests, Parmeter and Uhrenholdt (1975) have found that spore germination or mycelial growth of several fungi, including *Fomes annosus*, was reduced by exposure to smoke. By contrast, *Trichoderma* spp., common fungal competitors of *Fomes annosus*, increased in soil after

burning (Froelich and others 1978) and germination of Trichoderma spores was increased when exposed to smoke (Parmeter and Uhrenholdt 1975).

Age structure of lodgepole pine forests relates very strongly to potential for attack by mountain pine beetle (Dendroctonus ponderosae Hopk.); beetles first attack larger (14-inch diameter or more) trees which have thick phloem and a better food supply (Roe and Amman 1970). In addition, high-elevation stands show less infestation by pine beetles and greater infection by dwarf mistletoe (Amman 1969). Beetle activity in the absence of fire in the Northern Rocky Mountains leads to replacement of lodgepole pine by Douglas-fir at lower elevations and by subalpine fir and spruce at higher elevations. In the presence of fire, seedling lodgepole pine come in.

As an example, the 1961 Sleeping Child Fire burned more than 25,000 acres of lodgepole pine in the Bitterroot National Forest of Montana which had previously been heavily damaged by mountain pine beetle between 1928 and 1932 (Roe and Amman 1970). Lodgepole pine seedlings became established on about 15,000 acres of the burned area; within 80 to 90 years, these newly established pine trees will simultaneously reach sizes attractive to beetles over sizable areas. Then a widespread infestation of beetles will lead to heavy fuels which in time will lead to intense burning which may be followed by another restocking of lodgepole pine seedlings which will start the sequence again. In areas where mistletoe infection is heavy, tree growth is reduced, thus reducing the likelihood of beetle infestation. However, in that instance, the previously described changes in vertical structure which mistletoe brings about also lead to fire hazards and burning.

In ponderosa pine forests, Miller and Keen (1960) found that western pine beetle (Dendroctonus brevicornis) populations concentrate in fire-injured trees which survive a fire. They noted that unburned stands of ponderosa pine had larger numbers of small trees than burned areas, but that burned areas had larger trees and larger volume per acre. Thus, they concluded that in general, "...the long-term effect of fire is to lessen western pine beetle damage rather than increase it."

It would appear that man's efforts to decrease fire frequency often lead to conditions favoring growth of forest insects or disease organisms. Such growth in turn affects forest structure and fuel buildup in a way which insures the forest will burn, sometimes with greater intensity than would have been the case otherwise.

#### Stability, Diversity, and Resilience

Bonnicksen and Stone (1978) note that in the absence of frequent fire in sequoia-mixed conifer forests, there is not a steady state mosaic. Instead, younger aggregations are being replaced by older ones. There is no fire to make new openings and no opportunity for seedling and sapling white fir to become the top tier dominant in such new aggregations. Keeley (this volume) has suggested that frequent fires are an important part of the fire regime, because they preserve seed trees by preventing widespread crown fires among species such as ponderosa pine which have no means of storing seed on trees or in the soil. Under a periodic fire regime in a mixed-conifer ecosystem, Agee and others (1978) point out that ecosystem dynamics appeared to be more stable. Low decomposition rates and the flammable nature of the forest floor in this system assured that frequent surface fires would occur, periodically releasing stored energy.

"If stability is defined as the ability to resist change, then...vegetative cycles maintained and driven by fire must be considered to be stable" (Vogl 1970). As such, lodgepole pine communities and other fire types would be considered very stable, because fires in such types result in a replacement community of similar structure to that originally found there, while fire in climax types results in extreme change (Brown 1975). On the other hand, when natural fires are suppressed in a mixed conifer forest, biomass and energy accumulate, species composition shifts, the new system is

less flammable, ladder fuels build up in understory trees, and a wildfire which does occur is much more likely to become a high-intensity crown fire, killing mature trees and seriously disrupting the system (Kilgore and Sando 1975, Agee and others 1978).

Loucks (1970) believed that community stability, species diversity, and annual productivity are positively related. He offered the hypothesis that "...evolution in ecosystems has brought about not only adaptation to heterogenous environments, but adaptation to a repeating pattern of changing environments, a stationary process that represents a composite of time intervals over which replacement of species is repeated over and over again." As a part of their study of fire-dependent forests in the Northern Rocky Mountains, Habeck and Mutch (1973) offered a similar hypothesis that, "...the diversity of community life forms engendered some sort of ecosystem equilibrium or a kind of biologic 'check and balances' system that governed the magnitude of the effects accompanying a given forest fire." Taking this a step further, one could also assume that simplifying the community life forms by eliminating fire may modify forest structure in a way that brings imbalance to the natural system. Taylor (1973) found that elimination of fires in lodgepole pine communities in Yellowstone National Park, Wyo., limited ecological diversity by reducing or eliminating those plants and animals found only in successional communities present before closure of the forest canopy.

A different point of view is found elsewhere in the ecological literature. "Resilience" has recently been defined as "the ability of a natural ecosystem to restore its structure following acute or chronic disturbance..." (Westman 1978). This set of properties was included under the term "stability" in earlier work by May (1973), Holling (1973), and Orians (1975). Westman (1978) suggests that "stability" be limited to the "pattern of fluctuations in a relatively unimpacted ecosystem over time" and cites work by Whittaker (1975) to support this. The ability of a system to resist displacement in structure and function when subjected to a disturbing force (such as fire) has been referred to as "inertia" by Orians (1975) and Westman (1978). Holling (1973) had termed this same property "resilience," while Vogl (1970) had called it "stability."

Botkin and Sobel (1975) have pointed out that "stability" in the anecdotal literature has often been implicit and vague. Where it was defined, the concept was similar to the "static stability" found in a classical mechanics system that returns to equilibrium after being disturbed. Such definitions are found in Odum (1971), Krebs (1972), and Smith (1974). Holling (1973) and Botkin and Sobel (1975) contend that such a static stability concept, borrowed from classical physics, may be inappropriate for the analysis of ecosystems in that, "Natural undisturbed systems are likely to be continually in a transient state" (Holling 1973).

Using the example from Heinselman's (1973) history of the 100-year return interval for fire in the forest of the Boundary Waters Canoe Area of Minnesota, Botkin and Sobel (1975) maintained that the concept of an equilibrium state for a natural forest has been contradicted by history and that static stability is a concept with little ecological value. They ask the question: "What does it mean to 'stabilize' or 'preserve' a forest when the natural undisturbed forest is changing through time, and when fire appears to be an intrinsic event?" They feel that the analysis of stability and its dependence on ecosystem complexity must be broadened to include "notions of stability besides the definition of static stability borrowed from statistical mechanics."

May (1973) contends that in the natural world, "it is not true that population stability is uniformly associated with trophic complexity and faunal and floral diversity." On the contrary, a number of natural monocultures, such as the march grass (*Spartina alterniflora*), are very stable; the instability of man-made monocultures results not from their simplicity, but from their unnaturalness. As a mathematical generality, May (1973) contends that increasing diversity and complexity enhance

community instability. But he also notes that we need much better understanding of principles which govern natural associations of plants and animals. This can be primarily gained by studies in pristine ecosystems such as those found in National Parks and Wildernesses.

#### CONCLUSIONS

Fire suppression has caused an increase in intervals between fires in many areas. This decrease in frequency is leading to an increase in surface fuels in many forests and a modification of forest structure.

This structural change is manifested as a shift in the distribution of ages and species composition in various forests and scrublands of the West. In turn, these changes in age classes and species composition affect both the horizontal pattern and vertical structure of the forest. Such structural changes lead to significant modification in the vertical and horizontal fuel arrangement of the forest--including an increase in ladder fuels--and hence to changes in probable intensity of future fires. In many cases, these changes appear to lead toward higher intensity fires in forests which previously had frequent, low-intensity fires as a normal fire regime. Changes are less noticeable so far where long return interval, high-intensity fire regimes are involved.

Such shifts in frequency of burning--which lead to changes in structure--also modify the intensity of subsequent fires, and in turn can lead to substantial changes in postfire forest structure. This new and different forest structure can in turn lead to changes in both frequency and intensity of subsequent fires.

The complexities of these interactions in any given forest are further compounded by (1) the very large number of possible species combinations in various geographic zones and (2) the variations which topography and weather can bring to the impact of a given frequency and intensity of fire on various vegetation types.

There is great need for additional knowledge about natural fire regimes--involving both frequency and intensity--in many forest types of the West. But there is also need to take full advantage of what we already know and to apply this knowledge in management of our forest and scrubland ecosystems. In summary, as has been pointed out elsewhere (Kilgore 1976), we need better understanding of fire as a process and as a tool, but we also need greater commitment by land managers to use on the land the best of what we already know. To carry out an effective resources management program in western forests and scrublands, we will also need a well-trained cadre of fire managers who understand fire behavior under a variety of vegetation and weather conditions. To be fully successful as scientists, laymen, and environmentally concerned citizens, we must also work to gain greater public understanding of and involvement in developing and approving our land management practices.

Just as the fire process is basic to the operation of many ecosystems in the West, so our understanding of fire regimes is basic to our management of such ecosystems in National Parks, Wilderness Areas, and other public lands. With firmer knowledge and insight into how fire frequency and intensity relate to the structure of these systems, we can begin to use fire as a tool to best simulate its natural role in these areas.

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